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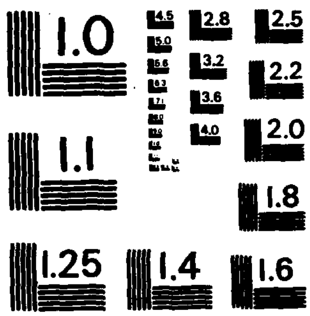

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The US Army Engineer Topographic Laboratories are currently investigating the automation of the cartographic generalization and displacement activities. This long-term effort will be divided into three phases: a study phase for examining present manual and computer-assisted methods of generalization and displacement; a research software phase for selecting, testing, and modifying promising algorithms; and a production software phase. The study phase was conducted by Zycor, Inc. and interim results are discussed in this paper. These include an analysis of generalization and displacement in the manual compilation process at the

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Defense Mapping Agency Hydrographic/topographic center and a discussion of the importance of understanding manual methods when develping computer-assisted and automated algorithms.

AUTOMATING GENERALIZATION AND DISPLACEMENT
LESSONS FROM MANUAL METHODS

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ABSTRACT

The US Army Engineer Topographic Laboratories are currently investigating the automation of the cartographic generalization and displacement activities. This long-term effort will be divided into three phases: a study phase for examining present manual and computer-assisted methods of generalization and displacement; a research software phase for selecting, testing, and modifying promising algorithms; and a production software phase. The study phase was conducted by Zycor, Inc. and interim results are discussed in this paper. These include an analysis of generalization and displacement in the manual compilation process at the Defense Mapping Agency Hydrographic/Topographic Center and a discussion of the importance of understanding manual methods when developing computer-assisted and automated algorithms.

INTRODUCTION

The Defense Mapping Agency (DMA) produces maps, charts, and digital information for use by the Armed Forces and other national security operations in the United States. It also produces nautical charts for a variety of non-military users. DMA's two main centers provide mapping services directed toward different military users. The Defense Mapping Agency Aerospace Center (DMAAC) concentrates on aeronautical charts and digital information for aviation purposes. The Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC) primarily produces tactical products for the Army and Air Force, and hydrographic charts for the Navy and civilian mariners. Maps and aeronautical charts produced by DMA are created at many standard scales, including 1:50,000, 1:200,000, 1:250,000, 1:500,000, 1:1,000,000, 1:2,000,000, and 1:5,000,000. Hydrographic charts are produced at a variety of scales.

Cartographic license plays an important role in DMA manual map and chart production, because the cartographer is permitted to adjust, exaggerate, or omit features within allowable limits. As a result of this license, the appearance of a map or chart may differ slightly if compiled and engraved by different cartographers or by the same cartographer at different times. Cartographic license affects the five primary mapping tasks: selection, classification, generalization, displacement, and symbolization.

The US Army Engineer Topographic Laboratories (USAETL) are currently conducting a long-term research effort for DMA directed at automating two of these tasks, generalization and displacement. This represents a departure from traditional research into the mechanical processes such as automated digitization and plotting, and transition to a new area, the quantification of subjective cartographic thought processes.

DEFINITIONS

Generalization and displacement (See Figure 1) are defined within the context of the Department of Defense Glossary of Mapping, Charting, and Geodetic Terms, 4th Edition, 1981.

Generalization - Smoothing the character of features without destroying their visible shape. Generalization increases as map scale decreases.*

Displacement - The horizontal shift of the plotted position of a topographic feature from its true position, caused by required adherence to prescribed line weights and symbol sizes.**

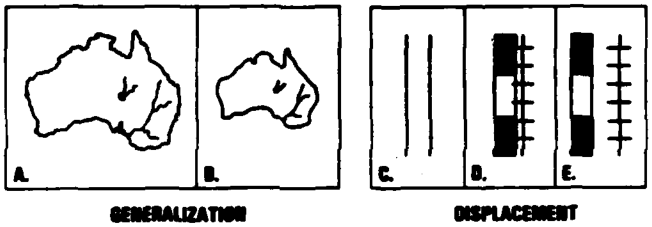

FIGURE 1

Generalization. An outline of Australia (A) is simplified (B) from the larger to the smaller scale portrayal.
Displacement. Nonoverlapping centerline data (C) overlaps when symbolized (D). Displacement (E) resolves the conflict.

The Department of Defense (DOD) definition of generalization is narrower than the definitions commonly in use in the academic community. Robinson, Sale, and Morrison define generalization to include four elements: simplification, classification, symbolization, and induction. (Robinson, Sale, and Morrison, 1978). Simplification is the determination of the important characteristics of the data, the retention and possible exaggeration of these important characteristics,

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* Department of Defense Glossary of Mapping Charting, and Geodetic Terms, 4th Edition, 1981. P. 65

** Ibid, p. 47

and the elimination of unwanted detail.[8] Thus, the Robinson, Sale, and Morrison definition of generalization has a broader scope than the DOD definition and the DOD definition closely corresponds to their definition of simplification. Monmonier defines generalization in terms of feature selection, geometric smoothing, and feature shifting. (Monmonier, 1982) In this case, geometric smoothing closely corresponds to the DOD definition of generalization.

AN APPROACH FOR AUTOMATION

The US Army Engineer Topographic Laboratories have adopted a three-phase approach for the automation of generalization and displacement. Phase 1 is a study phase in which the following subjects will be analyzed: 1) DMA manual and automated techniques, specifications, and requirements, 2) non-DMA algorithms and software, and 3) potential computer-assisted generalization and feature displacement algorithms for use at DMA. Phase 2 will be the development of research software based on the algorithm or algorithms recommended in Phase 1. Extensive test and analysis will be performed on candidate algorithms, enhancements made, and a final algorithm or set of algorithms will be selected for inclusion in production software. Phase 3 will be the development of production software.

It is anticipated that the effort to develop line generalization and feature displacement software will be completed in the late 1980s or early 1990s. Initially the software will be interactive and computer-assisted rather than fully automated. The Phase 1 study contract was awarded to Zycor, Inc., in Austin, Texas, in August 1982, and completed in January 1984. Interim results of the study phase relating to manual methods and their application to computer-assisted methods are discussed in the remainder of the paper.

MANUAL COMPILATION AND THE DEFENSE MAPPING AGENCY HYDROGRAPHIC/TOPOGRAPHIC CENTER

The various DMA centers are tasked with the generation of a wide variety of map and chart products. The sources, required scales, cartographic projections, content, symbology and formats vary widely depending on the final product. Thus, encountering differing compilation procedures among facilities is to be expected. To simplify the scope of this discussion, map compilation (See Figure 2) at DMAHTC of 1:250,000 Joint Operations Graphic (JOG) map sheets from a single source, 1:50,000 map sheets, will be described with specific emphasis on generalization and displacement. (Note: Additional map and photo sources would be used in actual production).

Map compilation is initiated by the creation of a Map Preparation Guide which outlines for a particular project the unique requirements for the product, guidelines for the horizontal control, cartographic transformation, a list of sources to be used, and references to the required map specification guidelines for the desired map scale. The

[8] Arthur Robinson, Randall Sale, and Joel Morrison, Elements of Cartography, 4th Edition, (New York: John Wiley and Sons, 1978, (p. 150).

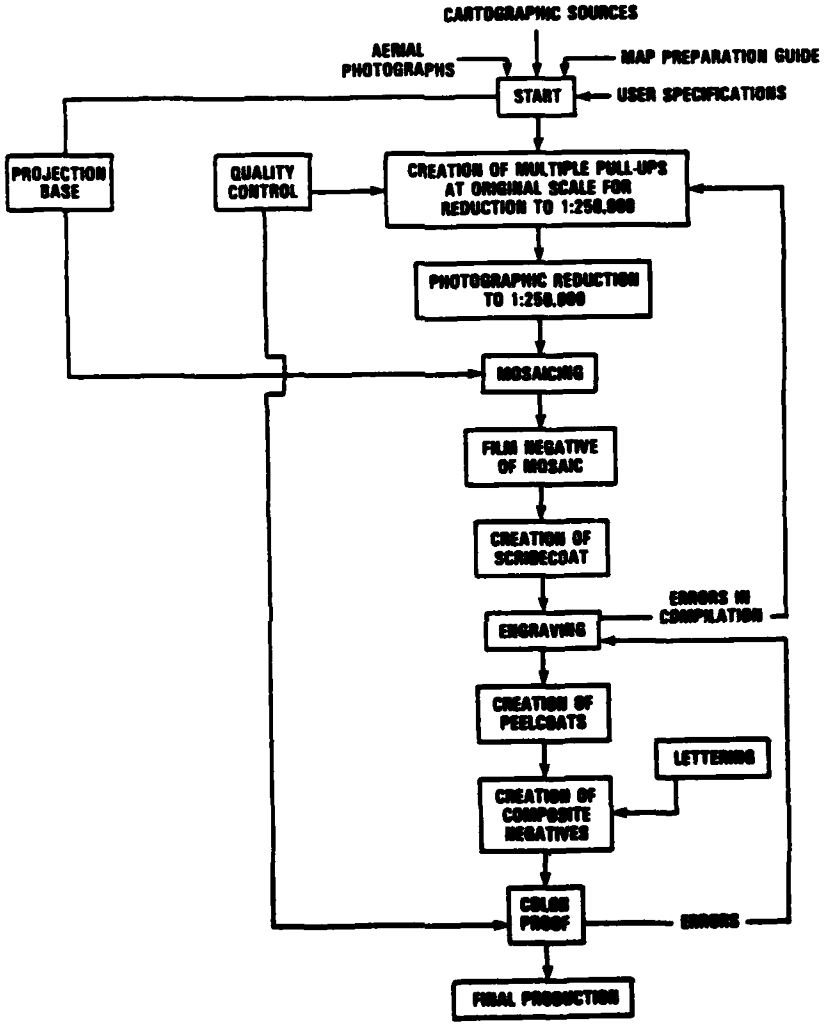

FIGURE 2

DMAHTC 1:250,000 Scale Joint Operations Graphic (JOG) Production Flow

"Defense Mapping Agency Product Specifications for Joint Operations Graphic Series 1501 and Series 1501 Scale 1:250,000," Fourth Edition, November 1976, provides detailed information on symbology, accuracy, selection of features, minimum feature separation, and annotation of the final product. Source materials in map compilation are obtained from maps, photographs and textual materials.

The 1:50,000 maps are used to generate pull-ups. A pull-up is a graphic enhancement on mylar of selected cartographic features from the map source. For 1:250,000 JOG sheets, three pull-ups are created: relief, drainage and culture, and vegetation. The creation of a pull-up involves the selection of features to be depicted, generalization, and displacement. The actual drawing is performed with a variety of pens, pencils, and felt tipped markers with line thicknesses that approximate the line thicknesses of the final product when the pull-up is photographically reduced. Thus, a 25-mil traced line is drawn on the 1:50,000 source pull-up to simulate a 5-mil line on the 1:250,000 final product.

This drawing technique aids both the generalization and displacement functions. By tracing lines on the source material using a line weight corresponding to the output line weight, the cartographer is able to smooth the representation of linear features. In most cases, a representation where the source line falls within the traced line is acceptable. Sometimes, however, greater generalization is needed and the traced line may deviate from the source line if exaggeration is required to adequately represent the line or feature of a smaller scale. In general, cartographers are directed to slightly overcompile or undergeneralize.

Feature displacement is also facilitated in the pull-up creation process. Because the traced lines are drawn to the target width, potential conflicts within the symbolized data are immediately apparent. Thus, if two parallel lines are close together, one line will maintain its position and the other line will be displaced to prevent symbol overlap. Guidelines on the priorities of features are provided in the map specification or auxiliary guidelines specific to the particular compilation section. For 1:250,000 topographic maps, drainage features are the most significant linear feature. They form the skeleton away from which all other data is displaced. In decreasing order of priority, other linear features include railroads, roads, power lines, and contours.

Once the pull-ups at 1:50,000 are completed, they are reduced to the target scale, 1:250,000, and mosaiced together. The photographic reduction produces the required change of scale, while the mosaicing is guided by geodetic control on UTM projection. The latitude and longitude tick marks are used to accurately place the photographically reduced pull-ups. Approximately 25 1:50,000 map sheets are needed to produce one 1:250,000 JOG sheet.

The final mosaiced document is then used in the engraving process. From the mosaiced document a film negative is produced for reproduction on scribecoat. The detail reproduced on the scribecoat is engraved manually and may be used to create the necessary peelcoats or open window negatives. These peelcoats are used for tinting areas of the map. During the production of the scribecoat and peelcoats, a lettering sheet and negative is also produced. Finally, composite negatives are created for each series of colors and a color proof is made to verify the registration and accuracy of the map. If no errors occur, the

composite negatives are used to make printing plates from which the maps are lithographed.

Both generalization and displacement may occur during the engraving process. Because the pull-ups can be created by different cartographers, the amount of generalization may vary from panel to panel within the mosaiced sheet. An experienced engraver can modify this information to obtain a uniform representative across the map by further generalizing line work which is undergeneralized. It is not possible, however, to add detail to line work which has been overgeneralized.

The engraver can also displace features. If it is apparent on the scribecoat that two or more symbolized features will overlap when scribed at the appropriate line weight, the engraver can shift the positions of the lower priority features.

A final check occurs at the color proof stage. A cartographer with experience in quality control reviews the map, including problems as a result of generalization and displacement. Corrections are usually made at the engraving stage, but it may be necessary to go back to the pull-up stage.

MANUAL PRINCIPLES APPLICABLE TO AUTOMATED TECHNIQUES

Computer-assisted or automated approaches offer the potential for standard and consistent approaches to generalization and displacement. A number of algorithms exist at present, but more refinement and sophistication is needed. Clues to guide development of advanced techniques may be found in map and chart specifications and guidelines as well as from conversations with cartogaphers. This is not to suggest that automated methods should mimic manual methods. Rather, manual methods provide a standard against which automated methods can be evaluated. The following cartographic and algorithmic considerations are important for principles developing software.

Cartographic Considerations

1. The locations of features should not change drastically during generalization or displacement. When generalizing features, "the lines should be basically as unchanged as possible from their large scale original positions, and only altered as much as is required for the legibility and clarity of the map and by the compatibility of the map elements."* Attempts to address this fundamental issue have been made by many of the existing automated algorithms. (Brophy 1973, Chrisman 1983, Christ 1976, Douglas and Puecker 1973, Ehrich 1973, Gottschalk 1971, Jenks 1979, Saloritsky 1974, Tobler 1964, and Vanicek and Woolnaugh 1975).

Displacement by definition requires the shifting of feature positions. A solution requires the establishment of feature priorities and separation rules. This permits maintenance of high priority feature positions, displacement of low priority features, and provides methods for resolving conflicts with features of equal priority. General

* Edward Imhof, Cartographic Relief Presentation, (Berlin: De Gruyter, 1982), P 132.

guidelines for priorities and displacement are provided in map specifications, but these do not cover every potential displacement problem.

2. A feature, not a line, is generalized. Computer-assisted algorithms are most often applied to lines rather than features, especially in the case of geomorphological features. It is easier to generalize a single contour line than to generalize a feature containing that contour line. At present, advanced techniques for identifying common geomorphological features such as spurs, cols, reentrants, etc., do not exist. The development of these identification algorithms is a necessary prerequisite for research into intelligent feature generalization strategies.

3. The association among features must be considered in generalization and displacement. Few automated generalization algorithms consider the association of features in the generalization process. In discussing manual techniques, Pannekoek observes, "Generalization of contours should always be carried out together with that of the drainage system, otherwise it may occur that on the map a river runs to one side of its valley or even on the ridge."*

Simple algorithms such as removal of the n'th point may unintentionally alter the topological relationships between features by creating intersections where none existed or eliminating existing intersections. Advanced algorithms must account for the interrelationships among features.

The association of features is especially significant for displacement. A proposed solution must not only identify and resolve a conflict, but identify and resolve any secondary conflicts resulting from the solution of the initial conflict. As an example, assume a stream, road, and water tower are adjacent, the symbolized stream and road overlap, and the stream maintains position. The displaced road must be checked to see if now the road and water tower conflict. If there is no overlap, the new positions may be maintained. If there is an overlap, additional displacement is needed. The limited research into displacement (Christ 1979, Schittenhelm 1963) is a result of the complex nature of the problem.

4. Differing classes of features may require differing degrees of generalization. It is often mistakenly assumed that the same amount of generalization may be applied to all features on a map. The amount of generalization applied to any given feature is dependent on the map's purpose. As an example, drainage is generalized the least on a 1:250,000 JOG sheet. Contours are considered background information and may be generalized more except in the areas around drainage and roads.

5. In addition to simplification, exaggeration and relocation are elements of generalization. Generalization may be assumed to merely be the reduction of existing feature data, but this understates the problem. The goal of generalization is to develop a representative pattern at the same or a reduced scale and this may involve both exaggeration and relocation. For example, a small spit of land

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* A. J. Pannekoeck, "Generalization of Coastlines and Contours," International Yearbook of Cartography, II, P 65.

containing an important point feature might be exaggerated on the pull-up larger so the spit and feature could be retained on the smaller scale map. Additionally, a stream that crosses a road a number of times in a short distance would be relocated to the side on which it predominantly resides, thus intentionally modifying the topology of the source material. Both modification and relocation may be necessary for developing a comprehensible cartographic product.

Algorithmic Considerations

1. In the near term, a computer-assisted solution is more practical than a fully automated solution. Due to the complex nature of generalization and displacement, a fully automated solution may not be attainable at present. Displacement has proved to be a computationally intensive task even when considering a small number of features. Generalization has been perceived as a more tractable problem, but this is due to the failure to consider the generalization of features rather than lines, the associations among features, and the development of representative patterns using exaggeration and relocation. Efforts should be directed towards improving present algorithms and developing advanced interactive edit techniques for resolving remaining problems. Fully automated techniques may develop with advances in artificial intelligence research.

2. A computer-assisted solution should be invariant with respect to origin, rotation, and scaling. The algorithms addressing generalization and displacement should not be significantly affected by the location of the first point processed, the rotation of the figure, or the scaling of the data. As an example, a generalization algorithm which selects every 3rd point will produce different representation of a feature depending on whether the first, second, or third point is processed initially.

3. A computer-assisted solution should be computationally efficient yet cartographically acceptable. This consideration is difficult to address due to the lack of definition for a cartographically acceptable solution. However, an algorithm developed for aeronautical, hydrographic or topographic mapping must assume that vast amounts of data will be processed (i.e., up to 2.4×10^9 one mil pixels for a 40" X 60" hydrographic chart in raster form). Elegance and accuracy must be weighed against computational efficiency and speed.

4. A computer-assisted solution should be controlled by a few simple parameters which may be easily understood by a cartographer. The effective use of an algorithm will depend on the cartographer's ability to understand the parameters incorporated in the algorithm or algorithmic and the individual and collective effects of parameters on the final product.

CONCLUSION

The path to fully automated generalization and displacement techniques begins with an understanding of manual methods and the development of computer-assisted techniques. Generalization algorithms exist at present, but more sophistication is needed. The basic elements of feature displacement algorithms need to be addressed and techniques developed for locating feature conflicts, and resolving them systematically using the rules and hierarchies from the specifications. The US Army Engineer Topographic Laboratories hope to address these problems over the next ten years.

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